Occurrence and management of basal stalk rot of water bamboo in Taiwan

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ABSTRACT

In 1999 a severe basal stalk rot disease of water bamboo (*Zizaniae latifolia*) occurred in Nanto County in the summer, and as of today Nanto is still the only county manifested with the disease. The causal agent of the disease was considered to be *Pythiogeton zizaniae*. The local varieties 'Green Shell Early' and 'Red Shell' were both susceptible, with the former being more susceptible. For the variety 'Green Shell Early', the edible swelling culms (water bamboo shoots) could be harvested in April–June and July–October, designated as the first and the second harvest period, respectively. The disease appeared from late April to October, but in July the disease severity scaled up to 43.8% in the individual field. The disease could cause severe yield loss of the second harvest period. For the isolation of this pathogen, the more distant from the cutting wounds the less frequent the pathogen could be isolated. By draining the field for 30 days near the end of first harvest period (around May and June), the disease severity could be reduced. Although the yield of the first harvest period was mildly decreased, that of the second harvest period was greatly increased, amounting to higher yield than the conventional farming. Planting water bamboo one month in advance and in combination with lighting at night could accelerate the harvest time, and accordingly draining was advised to be conducted earlier to reduce the disease severity and prevent the yield loss due to the drainage. Furthermore, the method treated with drainage and cut-off all the above ground plants post the first season would assist new tillers growth and significantly reduce basal stalk rot disease. The disease severity after treatment using the above-mentioned method was down to 1.4%, which was significantly lower than that of merely drainage treatment or non-drainage.

Keywords: *Zizaniae latifolia*, *Pythiogeton*, basal stalk rot, drainage, harvest period regulation

INTRODUCTION

Water bamboo (*Zizania latifolia* (Griseb.) Turcz. ex Stapf., syn. *Zizania caduciflora* Turcz.), also named as water shoots, water oat, Manchurian wild rice, and Coba, is a kind of perennial herbaceous aquatic plant. It has been cultivated in China for more than 2,000 years and in Taiwan for about 200 years. The plant is usually infected by a smut fungus, (*Ustilago esculenta* Henn.), which causes swelling of its basal culms [2, 3, 7, 11, 12, 14, 15]. The swelling culms, which usually grow under water, are consisted of plant tissue and fungal mycelia and have traditionally been used as a famous aquatic vegetable, named as water bamboo shoots, also called as *jiao-bai-sung*, *gau-sun* or *kah-peh-sung* in Taiwan [4, 8, 9, 13].

The largest water bamboo cultivation area in Taiwan is in Nantou County, especially in Puli Township. According to the Agriculture and Food Agency of the Council of Agriculture, there were 1600 hectares of fields in Puli planted with water bamboo in 2016. Those Puli fields represented 83% of all land in Taiwan planted with the crop, and they produced about 40,000 metric tons—92% of the nation's total output of water bamboo shoots.

There are two types of cultivars planted in Taiwan. The first one is a two-season crop plant, which is planted in the early spring and then can be harvested twice in the late spring to early summer (first harvest period) as well as in the fall (second harvest period); the other is the one-season plant which is planted in the late spring and then can be harvested once each year, in the fall. The first type is more popular than the second type because of high yield and quality, and 'Green Shell Early' is the most popular cultivar in Taiwan, which is also the main cultivar in Puli. 'Red Shell' is the major example cultivar of the second type of water bamboo in Taiwan. All plants grow in paddy fields with 45-60 cm deep of water in the growing season and the crops are renewed for the next planting season [9, 10].

In May of 2000, Puli experienced its first outbreak of basal stalk rot of water bamboo. Several hundred hectares of water bamboo were infected with the disease, and farmers' losses were heavy. Several researchers were sent to Puli to try to combat the outbreak. With the unsolved stem rot problem in hand, the researchers were confronted with an

additional issue the following year: The growth of the water bamboo was being stunted [(5)]. Fortunately, the researcher discovered the causal agents of the stem rot disease and the stunting disease of water bamboo and then developed several techniques to solve the basal stalk rot disease by utilizing the management methods of these two diseases without having to use chemicals[(6)].

Disease investigation and pathogenicity test of basal stalk rot disease

The disease occurred in summer of 1999 and continued to damage the water bamboo crop in the summers of the consequent years in Nanto County. The symptoms of the disease exhibited yellowing new leaves, basal stalk rot, stripe rot of the swelling culms, and even plant death (Figure 1A-J). In the summer seasons of 2000 to 2005, the disease spread from about 500 hectares to about 1000 hectares, mainly occurred in the intersection area of Mei River and Nankan River. Whereas, water bamboos grown in other counties have not shown any symptom of the basal stalk rot disease.

A detailed disease investigation was conducted in 2001 in two bamboo fields, which were nearby and owned by a farmer in Puli Township. One field (field A) showed the disease symptoms but the other (field B) didn't. Mild basal stalk rot disease occurred in field A since April one month after harvest. The disease reached the peak in July, with the highest disease incidence of 84.5% and disease severity 43.8%, and the disease incidence was down to 59.5% and the disease severity to 20.1% in October. No disease symptom showed in Field B in this year's observation. The yields of the first and second harvest period of field A were 11.2 and 11.8 km/ha, respectively, while those of field B 12.7 and 19.4 km/ha, respectively. 'Red Shell' water bamboo also exhibited mild basal stalk rot disease in near field in Puli Township during the disease investigation (Figure 2). *Pythiogeton zizaniae*, a new member of Oomycetes, was consistently isolated from the the diseased plants of the infected area. The pathogenicity was confirmed by artificial inoculation of water bamboo plants with zoospore suspension of the microorganism [(1)]. The pathogen caused disease symptom of the new tillers 1.5 month after artificial inoculation at the cut wounds generated during harvest.

Effect of irrigation water and cut wounds generated during harvest on the disease

In further field observation, necrosis usually started from the cut wounds generated during harvest and then expanded down to the healthy tissue (Figure 1K, L). The result

of the pathogen isolation confirmed the observation that the isolation ratios of *P. zizaniae* is 72, 78, 50 and 35% from the wound, sections 1st, 2nd, and 3rd, respectively. Other than that, the results of field trials showed that no matter whether water bamboo was planted in monoculture field soil or virgin soil, basal stalk rot will occur as long as the irrigation water used was from the upstream fields where the crops had the disease. Furthermore, the non-harvest plants as well as the plants in the fields with low-leveled irrigation water showed no or much lower disease incidence when compared with the harvested plants, which had cut wounds in the same test field.

Because the pathogen could produce movable zoospores that in turn could be easily spread to the whole field or other fields via irrigation water. The above results showed that the main source of the pathogen was from irrigation water in the fields, and the cut wounds generated during harvest were the main infection sites.

Draining irrigation water for disease management

Because the pathogens were spread through irrigation water and infected water bamboo through the cut wounds, drainage during the growing season could reduce the disease. However, drainage would affect the yield of water bamboo shoots because water bamboo grew poorly in paddy field without deep water. When draining the irrigation water near the end of the first harvest period for one month (about in May), it could reduce the disease incidence from 84.5% to 54.5% and disease severity from 38.8% to 24.3% in July, compared to the conventional field, which was irrigated the whole season. Although the drainage treatment reduced the yield of the first harvest period of water bamboo shoots from 12.8 ton/ha to 11.1 ton/ha, it prevented the yield loss of the second harvest period from 17.8 ton/ha to 13.4 ton/ha when compared to the conventional farming with irrigating during the whole growing season (Figure 3).

In further study, one-month-long drainage periods were respectively conducted in May, June, or July to estimate the effect of drainage on reducing disease severity of basal stalk rot. The result showed that earlier drainage (in May) could reduce disease severity and had a good yield of the second harvest period, but the yield of the first harvest period decreased. In contrast, late drainage (in July) had the best yield of the first harvest period, but disease index and yield of the second harvest period were the worst (Table1).

Combination of drainage, harvest period regulation and cutting off the shoots after harvest for disease management

Although earlier drainage (in May) could reduce disease severity and had a good yield of the second harvest period, it reduced the yield during the drainage period while the price of water bamboo shoots was higher than that in the second harvest period. Thus, farmers tried to plant water bamboo earlier in order to harvest earlier to prevent the yield loss during drainage in May. However, earlier planting led to a stunting disease, which was a physiological disorder (Figure 4A). Fortunately, another technique (night-lighting for 8 hours during the seedling stage) was developed to prevent the stunting disorder (Figure 4B). So earlier planting (with night-lighting) and drainage of irrigation water for 30 days in May could not only reduce the disease severity but also reduce the yield loss during drainage (Table 2).

Because water bamboo shoots were harvested underwater, the pathogen could be easily spread by irrigation water and then penetrate the crops from the cut wounds generated from harvest. The pathogen still colonized in the stem even if drainage executed after harvest period and would cause disease symptom of the new tillers. Further study showed that during the drainage period after the first harvest period, cutting off the stem and shoots above the ground and letting new tillers grow from the old stumps would significantly reduce the disease incidence and severity. The disease severity was 1.4%, significantly lower than that by drainage only (8.1%) or non-drainage treatment (13.2%). The yield was significantly higher than that of regular cultivation but only similar to that by drainage only (Table 3).

DISCUSSION

Because basal stalk rot pathogen, *P. zizaniae*, was mainly spread by irrigation water and infected the crops from the cut wounds generated during harvest, it could be easily understood that most of the water bamboo fields exhibited severe disease due to the irrigation water from the adjacent field. The pathogen might reach to the isolated or upstream fields by contaminated boots, machines, and equipment, and then spread downstream to other fields. That might be the reason why the disease spread to about 1,000 hectares in several years.

The pathogen would cause disease symptom of the new tillers 1.5 months after infection, so the crop showed severe symptom in June and July, 1-2 months after the peak of harvest while not many shoots left at that time. In July, the number of tillers was most severely reduced, which seriously affected the yield of the second harvest period.

Drainage in May (late harvest period) could reduce disease severity, but it reduced the yield in the drainage period. Planting water bamboo earlier in order to harvest earlier could prevent the yield loss due to early drainage in May and prevent the yield loss caused by the disease. However, earlier planting resulted in stunting growth, but nighttime illumination during the growth of tillers can avoid this problem.

Drainage and cutting off the shoot after harvest could avoid the basal stalk rot disease; regulating planting season with night-lighting at seedling stage in the short-day season could shift the harvest period to avoid yield loss during drainage. Utilizing the management methods for these two diseases, the researcher developed a unique system for regulation of water bamboo shoots during harvest period that made the growth of water bamboo shoots a year-round industry in Taiwan.

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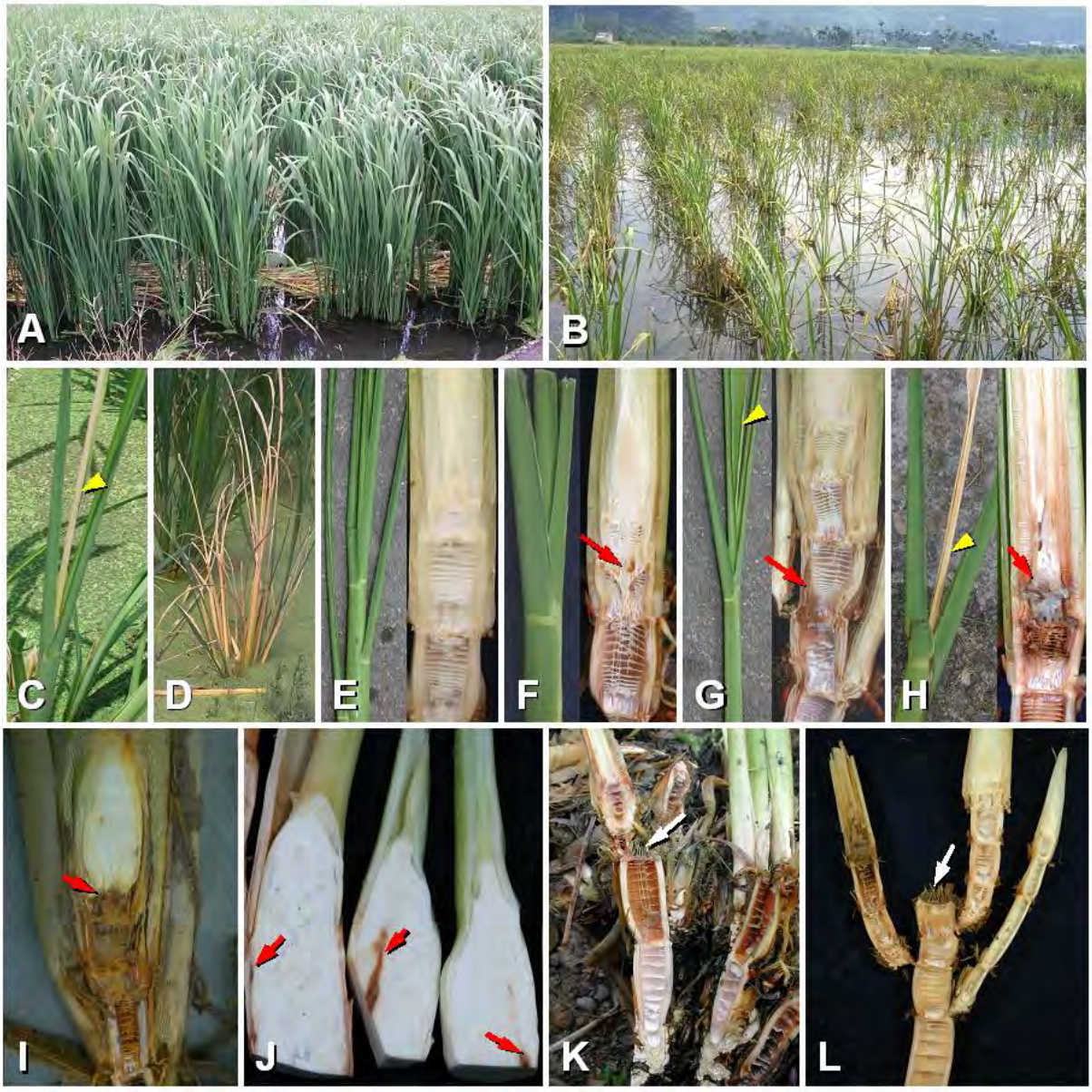


Fig. 1. Symptoms of basal stalk rot of water bamboo plants, healthy (A) and diseased plants (B) in the field. Basal stalk rot causing yellowing of new leaves (C) and death (D) of water bamboo. Leaves and basal stalk symptoms of healthy (E), mildly diseased (F), and severely diseased (G) water bamboos. Symptoms of basal stalk rot on eatable galls of water bamboo. Wilt or yellowing of new leaves (arrowheads) (H & I) whereas brown necrosis tissues (arrows) (J) caused by the disease. Cut wounds generated during harvest (arrows) and lateral stalk with basal stalk rot (K, L).

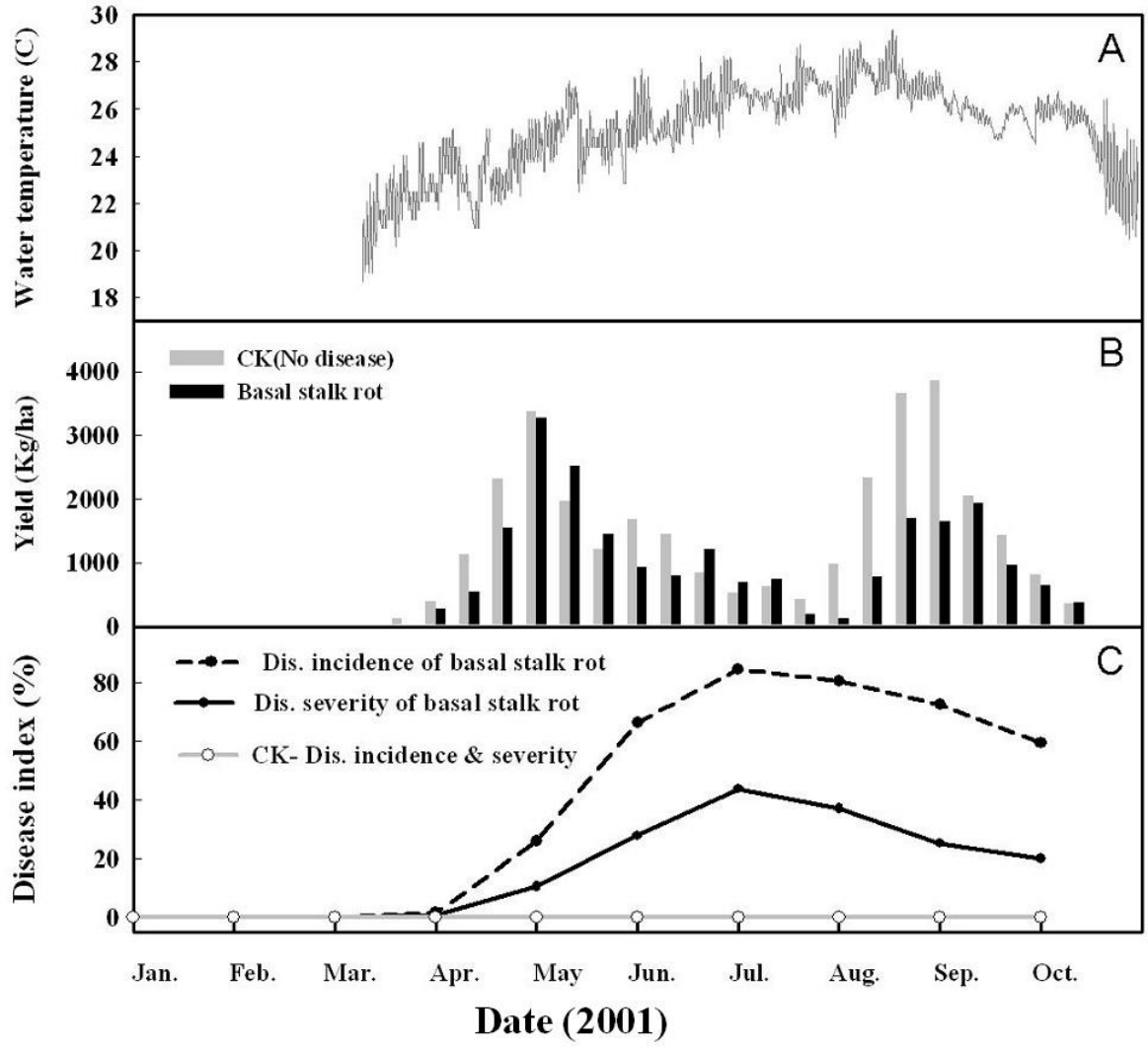


Fig. 2. Field water temperature (A), yields (B) and disease survey (C) of basal stalk rot of water bamboo at Puli. (Huang 2013)

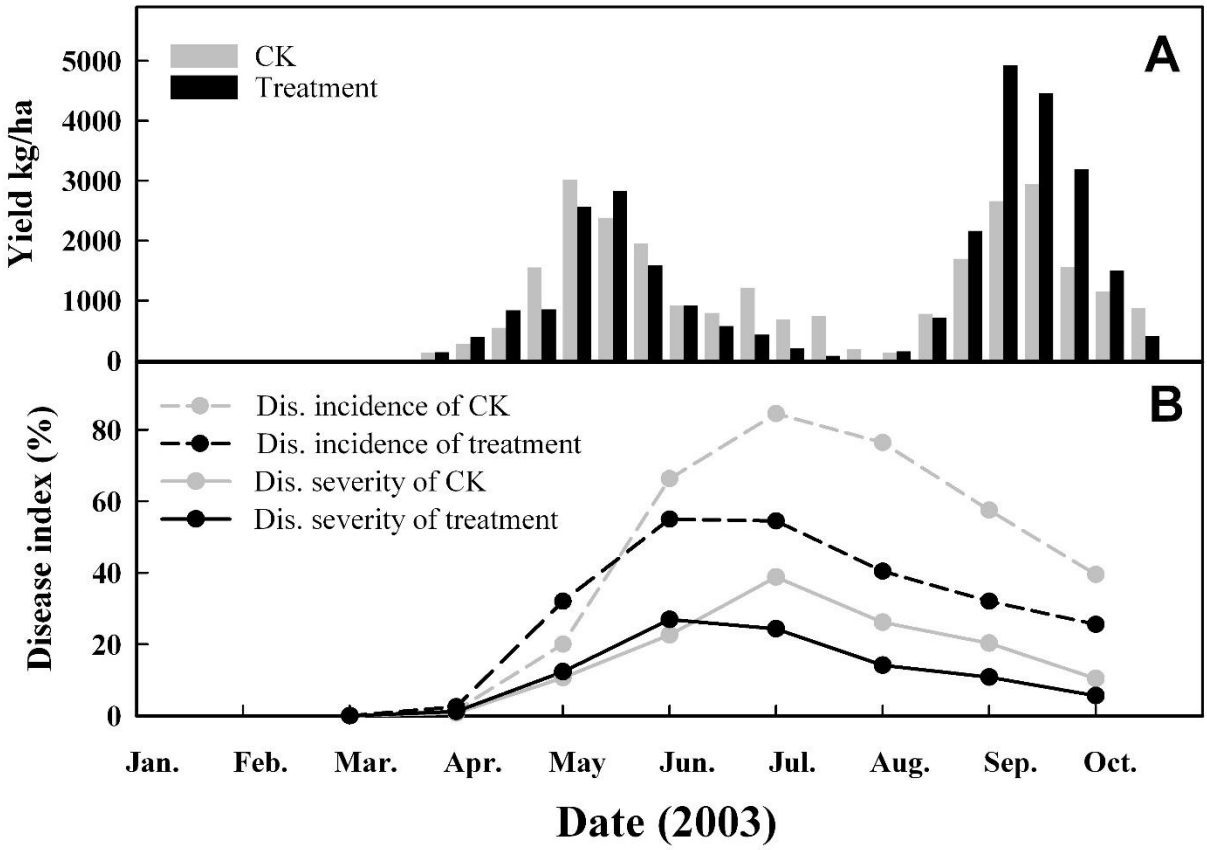


Fig. 3. Effect of drainage on water bamboo yield (A) and basal stalk rot disease (B) of water bamboo. CK: irrigated fields in whole season; treatment: drainage for one month from May 1st. (Huang 2013)

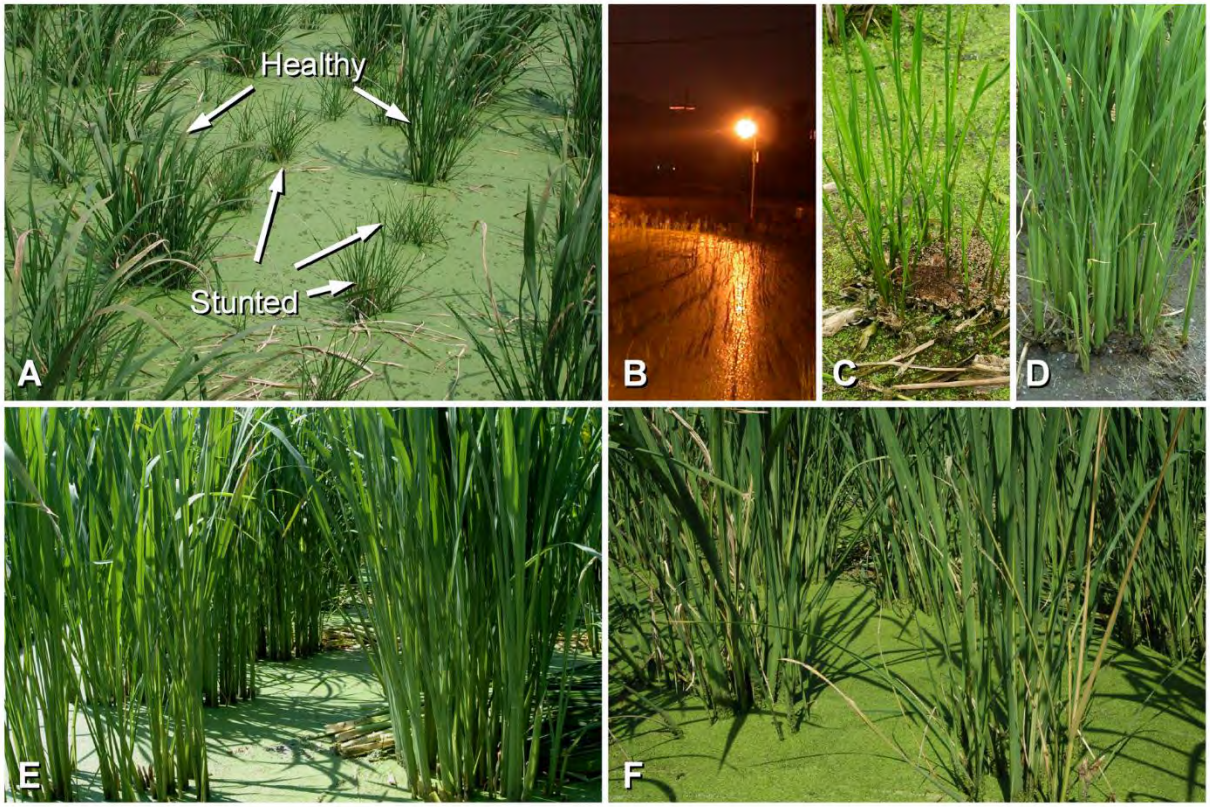


Fig. 4. Harvest period regulation with drainage after harvest for management of basal stalk rot of water bamboo. The stunted plants of water bamboo due to earlier planting in November (A), early planting accepted night lighting to prevent plants from stunting (B). Drainage after harvest and cutting old shoots off could promote the new shoots grow (C, D), and effectively decrease the basal stalk rot disease of water bamboo (E) as compared to the common cultivation process where the fields were irrigated whole season long (F).

Table 1. Effect of drainage period on the yield and basal stalk rot of water bamboo

Drainage period [1)]	*Dis. incidence % (Dis. severity %)*				*Yield (t/ha)* [1)]		
	May		*July*		*1st season*	*2nd season*	*Total*
CK	*21.5 a* [2)]	*(6.5 a)*	*89.0 a*	*(29.4 a)*	*9.7 a*	*13.5 c*	*23.2 b*
May	*19.0 a*	*(6.2 a)*	*57.0 b*	*(12.6 b)*	*6.3 b*	*21.4 a*	*27.7 a*
June	*22.0 a*	*(7.9 a)*	*71.0 ab*	*(17.4 b)*	*7.2 ab*	*19.8 a*	*27.0 a*
July	*18.0 a*	*(6.1 a)*	*81.0 a*	*(26.6 a)*	*9.1 a*	*16.2 b*	*24.3 b*

[1)]: First or second harvest periods mean the days before or after July 1.

[2)]: Means followed by the same letters within each column are not significantly different at p=0.05 according to the LSD Test.

Table 2. Effect of early planting with night lighting and drainage after first harvest period on the basal stalk rot of water bamboo.

Planting [1)]	*Drainage date* [2)]	*Dis. incidence % (Dis. severity %)*				Yield (t/ha) [3)]		
		May		*July*		*1st season*	*2nd season*	*Total*
Conventional	*No*	*12.0 a* [4)]	*(4.0 a)*	*89.5 a*	*(20.3 a)*	11.1 a	16.0 c	27.0 d
	Yes	*12.5 a*	*(3.3 a)*	*65.0 bc*	*(10.7 b)*	8.1 b	22.5 ab	30.6 c
Early	*No*	*15.5 a*	*(2.8 a)*	*77.5 ab*	*(16.8 a)*	12.3 a	19.6 b	32.9 b
	Yes	*9.5 a*	*(2.5 a)*	*61.0 c*	*(8.4 b)*	12.0 a	23.7 a	35.7 a

[1)]: Conventional: planting (nursery) at regular date (Dec. 1st, 2005) without night lighting. Early: earlier planting 45days earlier with night lighting for 60 days (8 hr/day).

[2)]: Drained the field water for 30 days from May 1st.

[3)]: First or second harvest periods mean the days before or after July 1

[4)]: Means followed by the same letters within each column are not significantly different at p=0.05 according to the LSD Test.

Table 3. Effect of drainage alone and drainage in combination with severed shoots after the first harvest period on the basal stalk rot of water bamboo.

Treatment [1)]	*Dis. incidence % (Dis. severity %)*		*Yield (t/ha)* [2)]		
	May	*July*	*1st season*	*2nd season*	*Total*
CK	*10.3 a* [3)] *(1.5 a)*	*65.0 a (13.2 a)*	10.5 a	20.5 b	*31.0 b*
A	*7.7 a (0.9 a)*	*47.3 b (8.1 b)*	11.7 a	23.4 a	*35.1 a*
B	*8.7 a (1.1 a)*	*10.3 c (1.4 c)*	11.2 a	22.2 ab	*33.4 ab*

1): All seedlings were planted in November 1st. CK: No drainage; A: drainage from May 1 to May30, but shoots were not severed; B: drainage in combination with all severed shoots.

2): First or second harvest periods mean the days before or after July 1.

3): Means followed by the same letters within each column are not significantly different at p=0.05 according to the LSD Test.